

## APPENDIX C

# *ADVANCE*

## Advanced Driver and Vehicle Advisory Navigation Concept

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Traffic Related Functions  
Evaluation Report (3 of 7)  
Documents # 8460.00

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### CONTAINS:

<b>Base Data and static Profile Evaluation Report</b>	<b>-- Document # 8460-O I.0 1</b>
<b>Data Screening Evaluation Report</b>	<b>-- Document # 8460-02.02</b>
<b>Quality of Probe Reports Evaluation Report</b>	<b>-- Document # 8460-03.01</b>
<b>Travel Time Prediction and Performance of</b>	
<b>Probe and Detector Data Evaluation Report</b>	<b>-- Document # 8460-04.01</b>
<b>Detector Travel Time Conversion and Fusion of</b>	
<b>Probe and Detector Data Evaluation Report</b>	<b>-- Document # 8460-05.01</b>
<b>Frequency of Probe Reports Evaluation Report</b>	<b>-- Document # 8460-06.01</b>
<b>Relationships among Travel Times Evaluation Report</b>	<b>-- Document # 8460-07.02</b>

Prepared by  
University of Illinois-Chicago  
Urban Transportation Center

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**ADVANCE   Evaluation**

**Quality of Probe Reports**

Siim Soot and Helen Condie

URBAN TRANSPORTATION CENTER  
University of Illinois at Chicago  
1033 West Van Buren Street  
Suite 700 South  
Chicago, Illinois 60607

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## **Executive Summary**

During the summer of 1995 approximately a dozen vehicles were driven almost 60,000 miles in urban traffic to assess the quality of data generated by probe vehicles. In this process over 55,000 link reports were recorded. These link reports provided information on at least three critical elements of travel: travel time, congested time and congested distance. This information was accumulated in the vehicle's on-board Mobile Navigation Assistant (MNA).

The driving occurred during the early afternoon and the pm peak period and included the hottest part of the day, in a summer which was one of the hottest on record. Many days were over 100°F and the MNA temperatures reached 150°F in some vehicles. Despite these extreme conditions, the equipment performed particularly well.

Two types of quality assessments were performed. The first considered the reasonableness of the data by evaluating speed and two congestion measures. The second assessment compared the probe data to data recorded by human observers. In the first evaluation less than three hundred suspect records (approximately 0.5% of all reports) were found; many could be traced to one faulty MNA. This is a commendable achievement. In the second evaluation, using human observers, the results were also good but not quite as precise. Considering travel time on the link and both congested time and congested distance the conclusion was that the match was sufficiently good between probe and human-observer data that the MNA data are a reliable indicator of traffic conditions.

A substantial amount of data was collected. In these data were some faulty records, but they constituted a very small portion of the total data collected and they were easily detected and deleted. As a whole the probe-vehicle data represent an especially valuable resource for traffic monitoring and analysis.

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# 1 Introduction

During the summer of 1995 approximately a dozen vehicles were driven four days a week over an eleven-week period. During this time almost 60,000 miles were driven to produce over 55,000 link reports within a confined study area. These reports provide information on at least three critical elements of travel: travel time, congested time and congested distance. This information is computed in the vehicle (also known as a probe) in its on-board Mobile Navigation Assistant (MNA) and it is recorded in two different ways, directly onto a diskette in the vehicle (the memory card) and by radio frequency to files tabulated at the Traffic Information Center (TIC) in Schaumburg, Illinois.

Data were collected on several study routes from June 5th to August 10th, Monday through Thursday. This data-collection exercise yielded the 50,620 TIC reports examined in this study.

It is the purpose of this report to evaluate the quality of these probe reports (also called MNA reports or link reports) by making several types of comparisons. The Evaluation Test Plan for Quality of Probe Reports called for a test of probe data and observer data for two variables? link travel time and congested distance. We encountered difficulty with observed measurement of congested distance so we expanded the testing to include congested time. Furthermore we also expanded the initial scope of our work by comparing link reports with expected results given link attributes. In summary we performed the following types of comparisons:

- comparing the MNA report data with expected results for three types of data
  - average link speed:
  - congested distance and
  - congested distance and congested time comparisons, and
- comparing the MNA report data with logs kept by human observers for three types of data
  - travel time,
  - congested distance and
  - congested time.

The first comparison is intended to discard any unreasonable data. The second is performed to assess the accuracy of the remaining data. Conclusions regarding these two comparisons cannot be made in a precise manner guidelines are provided for evaluating the usefulness of the data. It is not the intent of this report to explore the reasons for any faulty reports which may occur.

The overall assessment is that the on-board equipment performed very *well* but given the large amount of information collected there were also, understandably, faulty MNA reports. *Since this study examines mainly these faulty reports the reader may be left with the erroneous impression that the on-board navigation equipment did not function particularly well.* This is not true; based on reasonable expectations of vehicle travel speed and congestion data more than 99% of the reports convey useful data and the approximately half of one percent which appear faulty can be readily deleted by the user. The conclusions based on human observer data are not quite as strong but the utility of the data is again verified.

## **1.1 Background**

The first seven weeks (June 5 to July 20) consisted of driving on set routes centered on Dundee Road in Wheeling, Illinois (north suburban Chicago). Data were collected, with one exception, from Monday to Thursday. Fridays and weekend days were considered, for data collection purposes, to be different day types. The number of reports received on each day of probe data collection is shown in Table 1. This table includes only the data collected on the main Dundee Road study areas (see Section 1.2).

At the end of the Dundee Road data-collection period additional data were collected (August 14 - 18) on a nearby freeway segment (IL-53 / I-290) but the quality of these data could not be evaluated with the techniques used in the Dundee Road study area.

### **1.1.1 Driving Schedule**

At the beginning of each day of data collection, a twelve-noon briefing was held at the ADVANCE office in Schaumburg. At this time the drivers were assigned vehicles and they left the office at approximately 12:30pm. Each driver used a designated route to drive to the study area. There were several different routes; this report is not concerned with the routes to and from the study area. Data were collected by probe vehicles driven in the study area between 1pm and 7pm (Table 2), with breaks as described below.

The driving activity within the quality of probe reports study area generated over 55,000 reports received at the TIC, 50,620 of which are in the primary study area: these are examined in this report. After the memory card system was installed on July 20, 1995 on a typical day there were more memory card reports than reports transmitted to the TIC.

On each day of data collection a field manager was present at the staging area. The field manager ensured that vehicles were driving the study route at satisfactory headways and instructed drivers when to take breaks. The field manager also assisted with MNA failures and other problems which routinely occurred.

The drivers were given a ten-minute break at approximately 2:00pm to 2:10pm and another one from approximately 6:00pm to 6:10pm. Each driver took his or her break

Table 1: Probe Reports for each day of Data Collection

Date	No of Reports	Percent of Total
6/05	660	1.3
6/07	395	0.8
6/08	1140	2.3
6/12	1382	2.7
6/13	1712	3.4
6/14	1014	2.0
6/15	446	0.9
6/19	1178	2.3
6/20	1591	3.1
6/21	1503	3.0
6/22	2372	4.7
6/26	2037	4.0
6/27	1481	2.9
6/28	1744	3.4
6/29	1546	3.1
7/05	1560	3.1
7/06	1996	3.9
7/10	1689	3.3
7/11	1282	2.5
7/12	1507	3.0
7/13	1046	2.1
7/17	2285	4.5
7/18	2252	4.4
7/19	2140	4.2
7/20	1901	3.5
7/24	880	1.7
7/25	907	1.8
7/26	1017	2.0
7/27	899	1.8
7/31	949	1.9
8/01	1069	2.1
8/02	1038	2.1
8/03	1139	2.3
8/04	949	1.9
8/07	1058	2.1
8/08	1050	2.1
8/09	873	1.7
8/10	933	1.8
Total	50,620	100.0

Table 2: Probe Reports for each hour of Data Collection

Hour Beginning	No of Reports	Percent of Total
1pm	8464	16.7
2pm	7980	15.8
3pm	5187	10.2
4pm	8488	16.8
5pm	5433	16.7
6pm	7871	15.5
7pm	4197	8.3
Total	50620	100.0

at a slightly different time, as each was dispatched by the field manager to the break area as they arrived at the staging area. During breaks each probe vehicle was inactive for more than ten minutes as time was lost off-route and also while the vehicle and MNA warmed up. The longest break occurred for 3:30pm to 4:00pm. After this break, during the two-hour peak period from 4:00pm to 6:00pm, the drivers operated their vehicles without scheduled breaks.

### 1.1.2 Unusual Weather Conditions

The driving took place during the afternoon and early evening. The summer of 1995 was unusually hot and most of the driving was completed during the hottest part of the day. On several days the air temperature exceeded 100°F (38°C) and on the hottest day it peaked at an official 106°F (41°C).

These high temperatures proved to be a serious test for the MNA and without precautions the heat buildup in the trunk of the vehicle (where the MNA was located) caused system failures. The compact-disc unit reached temperatures in excess of 65°C (149°F) in some vehicles. Once the heat problem was recognized: special procedures were devised to alleviate the heat accumulation (opening the trunk to cool the unit during breaks and parking in a shaded area). These procedures substantially reduced MNA failures. Still, there were numerous occasions in which the MNA failed to transmit its activity to the TIC. Some vehicles also had their disk drives replaced, decreasing the MNA failures.

## 1.2 Study Area and Routes

The entire routes driven on Dundee Road and adjacent arterials were within the municipality of Wheeling, Illinois (north suburban Chicago). Dundee Road was selected because it carries a high volume of traffic and because each signalized intersection is demand actuated by loop detectors (including turning lanes) and there are volume and

occupancy detectors in several locations. Although Dundee Road extends for several miles within the ADVANCE study area the number of potential places along Dundee Road where the necessary field tests could be performed was very limited. The data-collection route required a convenient location where vehicles could turn around safely and avoid being off the study route for a long period of time. The route also needed a mix of link and intersection characteristics.

Two route configurations were used for the field data collection. The first route is the long route and was used for the majority of tests (Figure 1). The long route consists of twelve links. The section of the route on Schoenbeck Road and Palm Drive (near the west end) was used as a staging and turnaround area and since it was too short to complete a recognized link data were not collected for this section of the route. The route was selected to be completed during a fifteen-minute period. This provided the desired frequency of probe reports. Given the size of the driving fleet a longer route would not provide the frequency of reports needed for most tests performed. During the off peak the majority of the drivers completed this twelve-link route in ten to fourteen minutes.

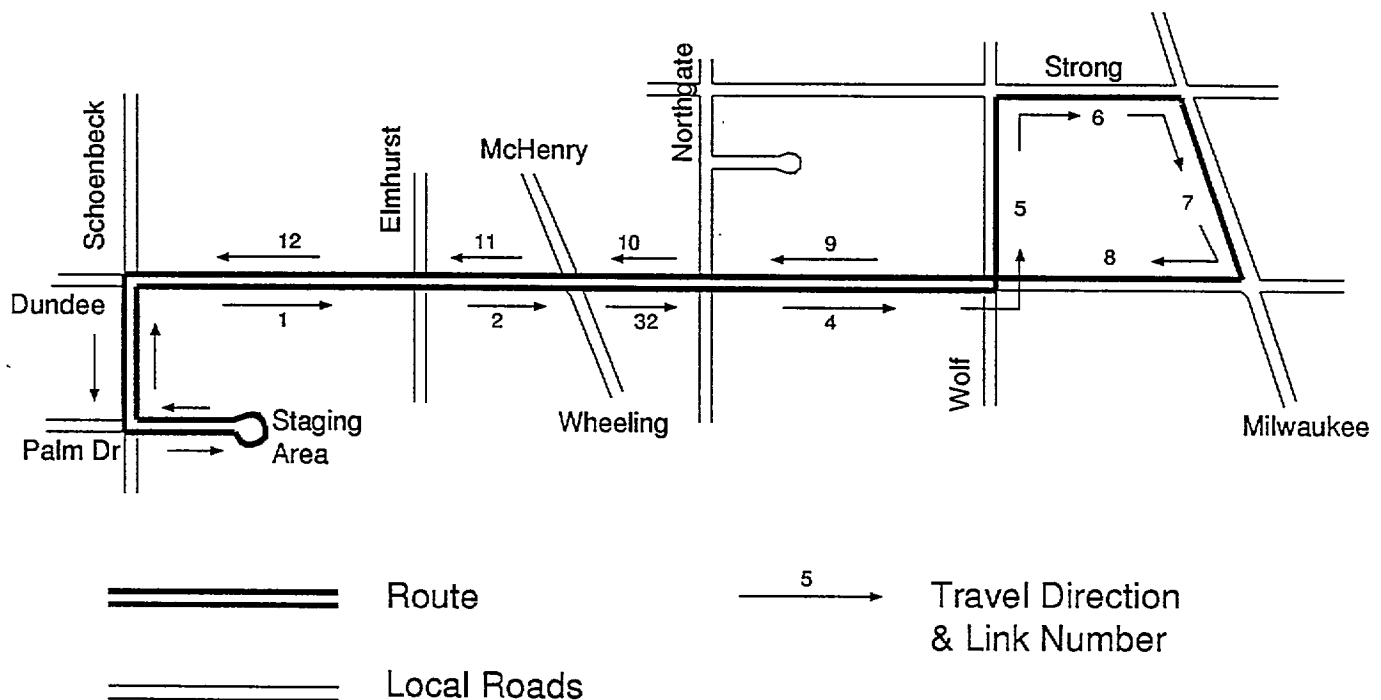


Figure 1: Probe Data Collection: Long Route

During the peak period this route proved to be too long to complete in fifteen minutes and a shorter alternative was used. This is shown in Figure 2. Even the short route could not always be completed in fifteen minutes but this happened infrequently.

Links 4 through 9 are on the long route but do not have the same number of link reports for two reasons (Table 3). First, many of the breaks were taken on this

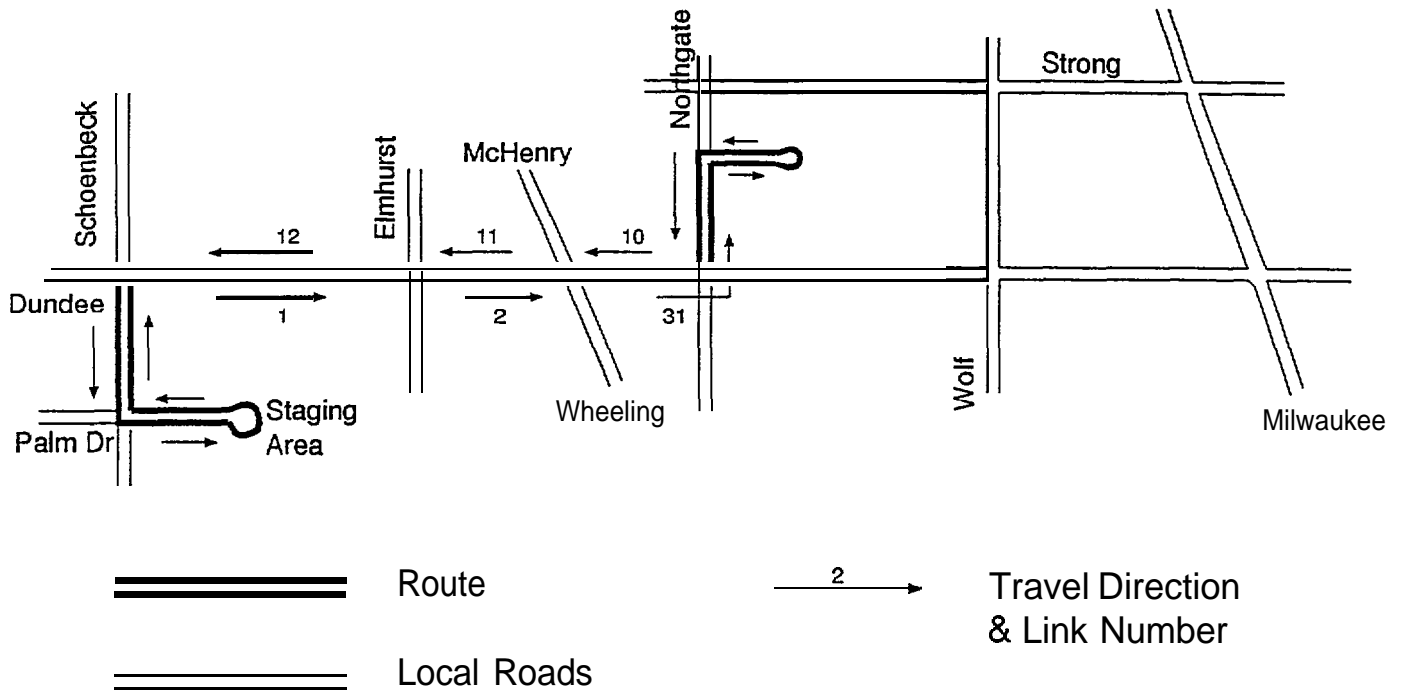


Figure 2: Probe Data Collection: Short Route

portion of the route. The most common break location was on Link 8 and there are correspondingly fewer reports on this link (the vehicles need to travel the entire link without stopping to create a report). Second, there may have been MNA failures and other reasons for turning off the link and stopping.

During the last three weeks in the Dundee Road study area the vehicles were being used to test turning relationships. In this case each driver was given a set of randomly drawn routes, to be driven in sequence, which covered the links shown on Figure 3. This consisted of fourteen uni-directional links. On Link H/h the drivers were permitted to stop and study the rest of the routes they had been assigned to drive. These days generally yielded more than 1500 usable MNA reports, over half of these are on Dundee Road and are used in this study.

Table 3: MNA Reports by Link

Link	Frequency	Percent	Link	Frequency	Percent
1	5481	10.8	7	2323	4.6
2	6298	12.4	8	2172	4.3
3*	5886	11.6 *	9	2462	4.9
4	2313	4.6	10	6066	12.0
5	2294	4.5	11	7826	15.5
6	2293	4.5	12	5206	10.3
31*	3555	7.0 *			
32"	2331	4.6 *			
			Total	50,620	100.0

\* Link 3 consists of two links, 31 and 32. Link 31 is on the short route and includes a left turn at the end of the link. Link 32 is on the long route and has a through movement at the end of the link (no turn).

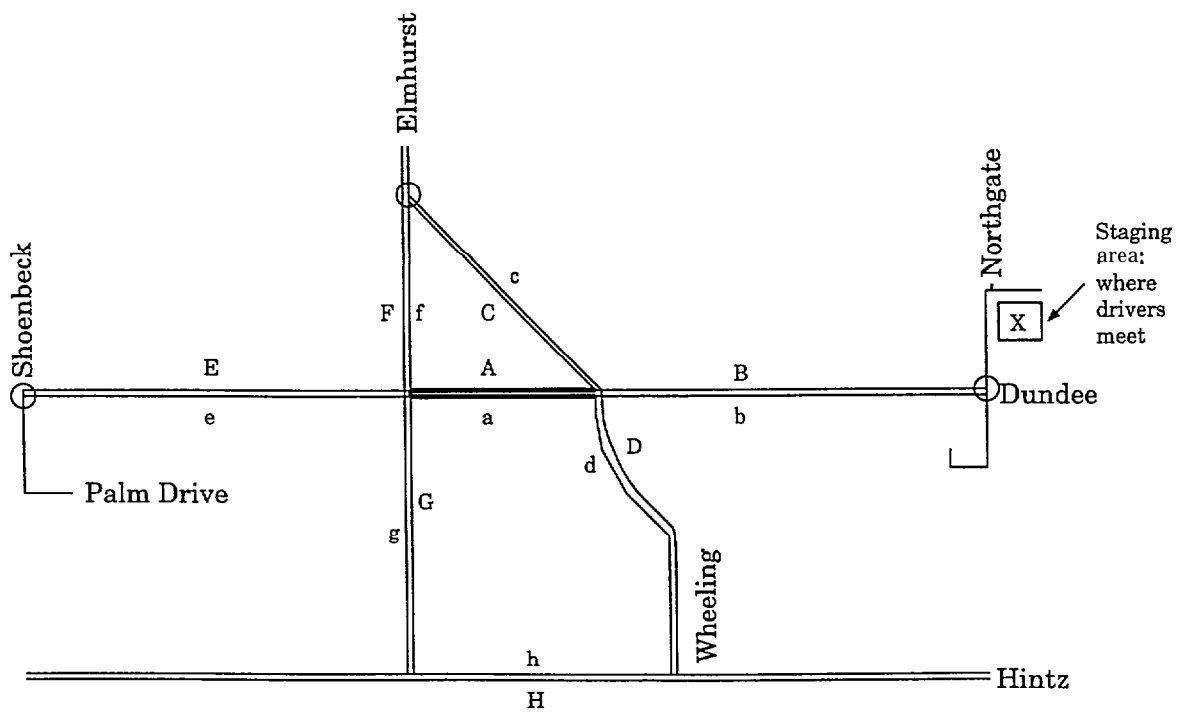


Figure 3: Probe Data Collection: Turning-Relationships Links

## **2 Information Processing in the Probe Vehicle**

Each probe vehicle is equipped with a substantial amount of electronic equipment. This includes a:

- computer,
- compact disc drive,
- radio transmitter and receiver,
- satellite signal receiver,
- RF Antenna,
- GPS Antenna.
- transmission sensor,
- compass/gyroscope,
- display head, and
- cellular telephone.

This equipment allows the probe to estimate its location and therefore to compute critical information, such as travel time, congested time and congested distance, which are examined in this report. The cellular telephone is included for general communication purposes.

The positioning of the vehicle is estimated with two complementary devices:

- the tracking system, and
- the Global Positioning System (GPS).

The tracking system is the principal positioning system and its location estimate is continually contrasted with the location specified by the GPS. When they differ significantly the GPS data are used to determine the probe location.

### **2.1 The Vehicle Tracking System**

The probe vehicle determines its location with a combination of four data items which come from:

- a sensor on the transmission to indicate travel distance,
- a gyroscope in the computer to specify the rate of turning activity,

- a compass to specify direction, and
- map matching to an electronically recorded (compact disc) map data base.

Initially the vehicle position can be manually entered by the driver or obtained automatically from the GPS. With the four pieces of information listed above, and its initial location, the MNA can update its location without the GPS.

## **2.2 The Global Positioning System (GPS)**

Each probe vehicle has a GPS receiver mounted on the exterior of the vehicle somewhere near the rear. This device receives signals from numerous satellites and estimates its position from these signals. Tree cover or other obstructions can interrupt the signals and cause momentary loss of the GPS. The GPS used by the probe vehicles provides a positioning estimate which is accurate to within 100 meters 90% percent of the time.

Since the GPS yields rather crude data the ADVANCE project uses a correcting system known as Differential GPS (DGPS). The error in the regular GPS at any given moment can be assessed by the GPS receiver at the TIC. The precise location of the TIC is known and the error correction is transmitted by radio to the probes. This provides a positioning estimate which is within five meters 50% of the time and within ten meters 95% of the time.

On the MNA monitor, mounted near the dash of the probe, the GPS position is marked by a green circle. When the differential signal is also being received there is a red ring around the green circle. This red ring also signifies that the radio communication with the TIC is active. There are times when the radio link with the TIC is interrupted, e.g., when the MNA is busy and is not servicing the communications port, and since the driver does not actively participate in the operation of the radio it is useful to have a means to indicate the status of the radio connection.

On occasions when the radio link went down for at least a two-minute period the drivers were instructed to stop the vehicle at a safe location and reboot the MNA. During rebooting time and for some period before rebooting no travel information was generated by the vehicle. MNA failure requiring rebooting occurred in several vehicles during a typical day. It is, therefore: often possible to locate a gap in MNA travel data received from a specific vehicle. In full deployment such gaps are not important to the TIC, in that they only lead to a loss of a limited amount of information. In analyzing the data collected in this evaluation it is important to know that involuntary gaps may exist in the data. This would also be useful information for someone tracking a given vehicle.

## **2.3 Data Preparation and Formatting**

The data received by the TIC from probe vehicles on the study routes was stored in decimal and hexadecimal form. The TIC data included reports sent by all ADVANCE

vehicles on all routes traveled. These data were reduced to include only the routes driven in the evaluation study area. The 60,000 miles driven therefore include all the miles accumulated by evaluation probes, but the 50,620 link reports refer only to those links on the study routes used for the quality of probe reports evaluation task.

The reduced data reports from the TIC are in easily readable form and include: date, time, travel time (TT), congested time (CT), congested distance (CD), and vehicle ID. We have added incident type (InT), incident duration (InD) and driver ID numbers to the MNA reports. The memory card data only include the first five variables.

### **3 Data Collection and Data Analysis**

#### **3.1 Suspect Speed and Congested-Distance Reports**

One aspect of the evaluation of the quality of probe reports was to compare MNA data with expected results from the probe vehicles. Two types of MNA data, for speed and congested distance, were compared with expected values in this way.

Since the drivers were instructed to drive with the traffic and to stay within the speed limit it is reasonable to expect that speeds recorded by the probe vehicles would not exceed the posted speed limits by more than 10mph to 15mph depending upon the speed limit. In order to identify excessive speeds the MNA data were examined in two phases. First we examined a two-week period in detail and then performed a more broad examination of the entire data-collection period. In the first phase speeds of greater than 50mph and 55mph were used in an effort to distinguish between reasonable speed excesses by the driver and problems with the MNA. In the second phase, data from the whole study period were analyzed to establish if any links or vehicles were responsible for a large number of high-speed reports.

Congested distances recorded by the probe vehicles for each link should not substantially exceed the length of that link. The same two-week sample of data was analyzed and CD reports which exceeded link length were identified. Data from the whole study period were then analyzed to establish if any particular links or vehicles were responsible for a large number of unusually high congested-distance reports.

#### **3.2 Observer-Recorded Data**

##### **3.2.1 Travel Times**

During the data-collection phase of the MNA evaluation observers rode in the probe vehicles and recorded the exact time at which the probe passed the beginning and end of a link. The data collected is summarized in Table 4.

Each observer was issued a digital watch which was synchronized with the clock in the TIC. The observers were instructed to record the exact time the vehicle passed

Table 4: Quality of Probe Reports, Manual Data Collected

Date	Observer ID	Car	Veh ID	minutes
June 1	15	Peugeot	22	20
		Tan Honda	20	179
June 22	1	Merc 320	13	81
		Merc 280	23	59
		Aerostar	65	31
		Windstar	87	58
July 6	15	Town Car	17	70
July 10	9	Sable	43	83
		Aerostar	65	113
July 10	4	Olds 98	27	132
		GMC Jimmy	10	162
July 11	3	Windstar	87	100
		Black Honda	21	132
		Bonneville	11	29
July 18	3	Peugeot	22	19
		Merc 280	23	17
		Lumina	16	45

through the middle of the intersection marking the beginning/end of a link. This is illustrated in Figure 4.

There are two conditions under which the observer time and the MNA time might not match. First, if the vehicle has had to come to a stop and is the first vehicle in the queue behind a traffic signal. Given the accuracy of the vehicle positioning system: it may be possible for the vehicle to record that it had passed through the intersection and therefore was recording time on the next link. Second, and much more likely is the uncertainty the observer has about when the probe has completed the link on a turn. There are at least two turns in the long route (Figure 1), one left and the other right, which may cause this type of uncertainty. On the left turn from Dundee Road to Wolf Road there is a left-turn lane and in cases when the turning vehicle must wait in the middle of the intersection to allow opposing traffic to pass before turning, the probe sits in the middle of the intersection and it may be unclear exactly when one link ends and the next begins. This problem then affects two links (Numbers 4 and 5) in which both recorded travel times are offset by about the same number of seconds, one in the positive direction and the other in the negative direction.

The same situation occurs at the Strong and Milwaukee intersection (Links 6 and 7). On this right turn there is a stop sign and probe vehicles typically need to move slowly forward to have the visibility to ensure that it is safe to proceed. It is not uncommon

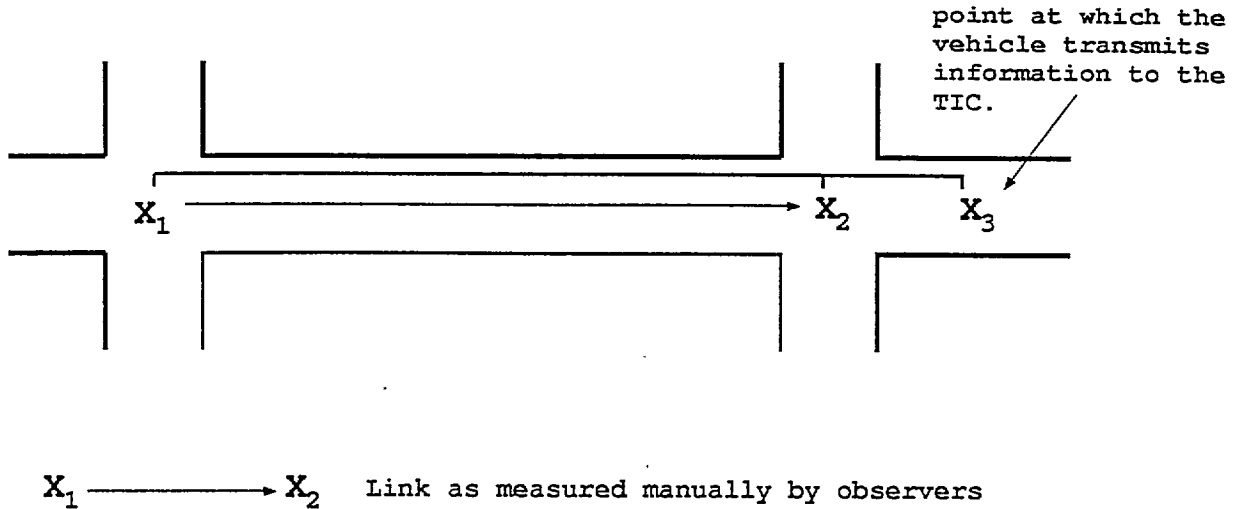


Figure 4: Link Measurement by Observer and MNA

to sit at this intersection, especially during congested periods for 5-10 seconds. Again it is hard to estimate when the vehicle positioning system makes the switch from Link 6 to Link 7.

In addition, it is possible the observers were distracted from the task of noting down travel times, e.g., by talking with the driver of the vehicle. It is not likely that an observer can remain alert for the many hours required to perform this task. This may explain some of the mismatches in MNA versus manually-recorded travel times. A common error made by the observers was to incorrectly write the minute of the recorded time. For example, if the start of the link was at 16:34:50 and the end was 16:34:05 and furthermore the end time of the next link was at 16:35:22 and these two links were of approximately the same length, we know there is a recording problem. In addition to the first travel time being impossible (-45 seconds), the first link is understated by 60 seconds and the next link is overstated by 60 seconds. Since the observers were concentrating on the seconds on the digital watch rather than the minutes, the minute digit was on occasion written incorrectly. These recording errors were easy to identify and they were corrected.

### 3.2.2 Congested Distance

Congested distance is measured in meters for each link and is the distance traversed by the probe vehicle at a speed of less than 10 meters per second (22.5mph). Congested distance is recorded by the MNA in the probe vehicle and transmitted to the TIC. In the congested-distance field test probe vehicles were driven over a known distance (e.g., between two fixed points or over the entire length of a link) at a speed below 22.5mph, then over a known distance at a speed greater than 22.5mph. In this way

the distance in meters driven at a speed less than 22.5mph is known and should match the congested-distance report from the MNA.

### **3.2.3 Congested Time**

Congested time is measured in seconds and is the time during which the vehicle is stationary or traveling at a speed of less than two meters per second (4.4mph).

To manually record congested time observers rode in the probe vehicles and recorded the exact time during which vehicles were stopped or traveling at speeds below 2 meters per second for each link. Most of the congested time is logged when the vehicle is at a complete stop.

Slow-moving traffic through intersections makes it difficult for the observer to know to which link the congested time needs to be applied. Compounding this difficulty is the coordination which is necessary to ensure that the observer records accurately the time at which the vehicle is moving below speeds of two meters per second (approximately 4.4 miles per hour). Both the beginning and the end of the congested time are subject to this coordination error between the driver and the observer. Two persons are recommended for this task since the driver can announce the moment the vehicle passes the two meters per second mark and the observer can be focused on the watch. This is not an easy evaluation task and, realistically, great precision is not possible.

## **3.3 Memory-Card Data compared to TIC Data**

The ADVANCE system is designed to store driving data on two different media. The link reports are recorded in the probe on memory cards and they are also transmitted by radio to the TIC.

Because of a number of factors not all link reports reach the TIC. There are also some reports which are excluded because they do not yield useful information. U-turns are the best example of this. Since this maneuver is not important to the link travel times (in fact it can potentially be confusing) it is not transmitted to the TIC. Many of these reports are, however, recorded on the memory cards. On this basis alone there should be more memory card reports than TIC reports. However, since the instructions to probe drivers were very precise (for example, not to make U-turns) there should only be a few cases which would result in reports which would not be transmitted to the TIC.

The most elementary comparison is the *number* of reports recorded by the TIC and by the memory card. The July 20, 1995 data for Vehicle 17 were compared. The results of this comparison are given in Table 21 in the Appendix. Regarding the quality of data, the information on the TIC and memory-card reports was identical on all records examined and the discussion in the next section on data quality applies equally to TIC and memory card reports.

## **4 Suspect Speed and Congested-Distance Reports**

Data collected during two weeks, June 19-22 and July 17-20, were analyzed to establish if reports sent from the MNA to the TIC contained unusually high speed or congested-distance data. In addition data collected during the entire data-collection exercise were analyzed to establish if particular links or vehicles were sending high numbers of suspicious speed and congested distance reports. It is again worth emphasizing that the overall quality of data is good but it is useful to explore where faulty reports occurred.

### **4.1 Suspect Speed Reports**

High-speed reports are defined as those reports in which the average speed for the probe vehicle on a link is substantially higher than the speed limit. Probe-vehicle drivers were instructed not to exceed the speed limit but since they were also instructed to drive with the traffic it is possible that speed limits were exceeded and the high speed was not obvious to the driver. On half of the links in the study area the speed limit is 35mph; on Links 1, 9, 11 and 12 the speed limit is 40mph and on Link 6 the speed limit is 25mph. We, therefore, make special note of speeds over both 50mph and 55mph and will determine from the sample June and July data which is the appropriate upper limit.

#### **4.1.1 June and July Sample Data**

Table 5 includes the high-speed reports (average link speed greater than 50mph) from data collected during the week of June 19-22. It may be seen from Table 5 that of 6644 MNA reports collected during this week, thirteen reports gave unrealistically high link speeds. Most of these speeds are clearly unrealistic while the last two are unlikely to be accurate readings but not beyond the realm of possibility. All of these thirteen speeds are above 55mph and therefore this does not provide clues about a realistic upper limit.

Five high-speed reports were received from Vehicle 65 and two high-speed reports were received from Vehicle 14. The high frequency of Vehicle 65 suggests a problem with this unit.

There is also a pattern with links. Links 9 and 10 together account for approximately half of all the high-speed reports recorded during this week in June.

None of these high-speed reports show incidents recorded by the driver. The most common incidents, such as cycle failure ( $InT = 1$ ) and train crossings ( $InT = 4$ ), occur on some links but it is logical that they would not be found in these high-speed circumstances. In the system of coding incidents the other values were 2 and 3 for turning and through movement blocking traffic, 5 for construction, 6 and 7 for MNA problems. 8 for being off the designated route and 9 for weather related traffic problems. e.g.. heavy rain.

Seventeen high-speed reports. with speeds over 50mph. were found in the 8578

Table 5: High Speed June 19-22

Date	Time	TT	CD	CT	Link	Vehicle	InT	InD	Speed( mph)
6 19 95	18 19 21	6	0	0	10	14	0	0	150
6 20 95	16 25 41	13	0	0	2	27	0	0	78
6 20 95	17 52 3	10	42	0	10	65	0	0	90
6 20 95	18 51 11	12	0	2	11	65	0	0	85
6 20 95	19 5 18	23	38	0	12	65	0	0	80
6 21 95	16 54 37	4	19	0	9	9	0	0	479
6 21 95	17 30 58	6	50	0	9	21	0	0	319
6 22 95	14 31 38	3	24	0	32	65	0	0	300
6 22 95	17 14 19	12	41	0	10	16	0	0	75
6 22 95	18 29 0	8	12	0	31	21	0	0	112
6 22 95	18 38 0	4	19	0	9	13	0	0	479
6 22 95	18 39 8	27	52	17	12	65	0	0	68
6 22 95	19 18 26	18	0	0	2	14	0	0	57

MNA reports collected during the week of July 17-20 (Table 6). Five of these reports are between 50mph and 55mph and they all occur during the off-peak. Moreover they are all less than 52mph and since they report no congested distance and no congested time they appear to legitimately portray free-flow conditions and as such should not be deleted. They likewise show no incidents.

Two of the seventeen high-speed reports: on the other hand, give average link speeds of 59.0mph. These do not appear to be an accurate reflection of the conditions. The first 59.0 mph report, on July 17, is for Link 8, a part of Dundee Road with alot of frontage access and considerable traffic. The second report, on July 18, shows a cycle failure lasting 179 seconds. This clearly is inconsistent with the thirty-one second travel time on this link. These two tables, then, suggest that 50mph is too strict and a 55mph is a more reasonable limit for discarding reports on the basis of speed.

Four high-speed reports were received from Vehicle 9 and two high-speed reports were received from Vehicles 13, 27 and 43. It appears that the problems of Vehicle 65, found in the June data, have been corrected but Vehicle 9 now has a problem. As a whole, the magnitude of the errors in July is considerably smaller that the June errors.

Five of the high-speed reports were recorded on Link 8 and three on Link 9; only one high-speed report during this week in July comes from Link 10 (cf. the June data). Consequently, the evidence here suggests that the relationship between links and problem reports needs further study, as pursued in the nest section.

Table 6: High Speed July 17-20

Date	Time	TT	CD	CT	Link	Vehicle	InT	InD	Speed(mph)
7 17 95	14 42 02	18	0	0	32	23	0	0	50.1
7 17 95	17 25 56	20	0	0	1	9	0	0	91.4
7 17 95	18 15 10	20	0	0	2	87	0	0	51.1
7 17 95	18 31 09	25	20	0	8	20	0	0	59.0
7 17 95	18 40 09	37	0	0	9	43	0	0	51.8
7 17 95	19 02 09	20	0	0	2	87	0	0	51.1
7 18 95	14 59 18	28	0	0	9	9	0	0	68.4
7 18 95	18 27 57	18	0	0	32	13	0	0	50.1
7 18 95	18 16 03	20	0	0	s	13	0	0	73.8
7 18 95	18 31 53	20	0	0	8	17	0	0	73.8
7 18 95	18 51 37	14	65	0	5	22	0	0	81.5
7 18 95	19 02 39	31	90	4	1	27	1	179	59.0
7 19 95	13 28 30	8	0	0	8	27	0	0	184.5
7 19 95	14 33 13	20	0	0	9	43	6	180	95.8
7 19 95	15 54 32	25	4	21	4	9	0	0	76.7
7 19 95	18 30 55	14	20	0	10	9	0	0	64.4
7 20 95	18 6 36	6	37	0	8	14	1	60	246.1

#### 4.1.2 All Reports

Data collected during the ten-week data-collection exercise were analyzed to establish if probes on particular links sent large numbers of high-speed reports. The number of high-speed reports (when average link speed is greater than 55mph as suggested in the previous section) for each link on the study route is shown in Table 7. These reports account for less than 0.2% of all probe reports, or less than two per thousand.

More than one quarter of the 87 high-speed reports (25 reports) were on Link 10; Links 8 and 9 each account for over 10% of the total high-speed reports. Link 10 is a moderately short link which passes over a rail crossing; it has only one access near the west end from a shopping complex.

The number of high-speed reports (when average link speed is greater than 55mph) for each vehicle used in the ten-week data collection exercise is shown in Table 8. Vehicle 65 (25 reports) accounts for over one quarter of the 87 high-speed reports; Vehicle 43 (11 reports) accounts for over one fifth of the high-speed reports. None of the other vehicles sent more than 7% of the total number of high-speed reports. This suggests a problem with two MNAs.

It is appropriate at this point to consider whether drivers contributed to these reports. It should be noted that no driver was assigned the same vehicle more than once a week and in most cases several weeks passed before an individual drove the same

Table 7: Reports where Speed exceeds 55mph: by Link

Link	Frequency	Percent		Link	Frequency	Percent
1	8	9.1		7	1	1.1
2	8	9.1		8	13	14.8
31 *	2	2.3		9	14	15.9
32 *	7	8	0	10	25	28.4
4	3	3.4		11	2	2.1
5	1	1.1		12	3	3.4
6	0	0				
				Total	87	100

\* 3 - short route (left turn)      \* 32 - long route (no turn)

Table 8: Reports where Speed exceeds 55mph: by Vehicle

Vehicle	Frequency	Percent		Vehicle	Frequency	Percent
9	6	6.9		23	2	2.3
10	4	4.6		25	1	1.1
11	2	2.3		27	5	5.7
13	2	2.3		43	11	12.6
14	3	3.4		62	3	3.4
16	4	4.6		65	25	28.7
17	1	1.1		69	2	2.3
19	1	1.1		87	2	2.3
20	3	3.4		89	2	2.3
21	3	3.4		92	2	2.3
22	3	3.4				
				Total	87	100

vehicle again. A random assignment was attempted but because the vehicle fleet and pool of drivers changed daily, this was not implemented as initially designed. However, an effort was made to cycle drivers through all of the vehicles.

All days with multiple high-speed reports were examined. Table 9 shows that while Vehicles 65 and 43 are responsible for a large proportion of the high-speed reports, these high-speed reports appear to be associated with the vehicles and not with drivers. Here 50mph is used rather than 55mph to broaden the scope in determining the role of drivers.

Table 9: Multiple Reports over 50mph Speed by a Vehicle in One Day

Date	Vehicle ID	Driver ID	Number of Reports
Aug 1	19	4	2
June 12	43	7	4
June 13	43	17	7
June 27	43	2	3
June 29	43	4	2
June 20	65	21	3
June 22	65	3	2
June 26	65	6	13
June 27	65	12	2
July 11	65	9	2
July 12	65	13	2
July 17	87	11	2
July 31	92	7	2

Note: All other vehicles produced no more than one 50+ mph report per day.

## 4.2 Suspect Congested-Distance Reports

High congested-distance reports are those reports where the congested-distance exceeds the link length. The link lengths for each of the twelve links on the study route are given in Table '10.

Initially the sample two-week data in June and July include those reports where the recorded congested-distance exceeds the link length by more than twenty-five meters. Since the error can be attributed to each of two link ends the error can be considerably more than twenty-five meters. but this is a good starting point. With a measurement from an odometer we cannot anticipate great precision. Accordingly, in the analysis which uses all data collected during the study period the high congested-distance reports presented are those where the recorded congested-distance exceeds the link length by at least 10%. We can assume that reports which exceed the link length by less than

10% are valid 'reports, conveying highly congested circumstances, but when the excess is more than 10% then we believe it is no longer appropriate to keep this probe report in the data set. Note also that the length of the link may not be accurately recorded in the roadway attribute data base and some tolerance should be allowed for this possibility.

Table 10: Study Route: Link Length

Link	Length (m)	Link	Length (m)
1	817	7	320
2	457	8	660
3	403	9	856
4	857	10	403
5	510	11	457
6	482	12	817

#### 4.2.1 June and July Sample Data

Table 11 includes the high congested-distance reports from the data collected during the week of June 19-22. During this week, of the 6644 MNA reports collected, eight contained high congested-distance reports. Two high congested-distance reports were received from Vehicle 65 and two high congested-distance reports were received from Vehicle 16. Although none of the high CD data of Table 11 matches the high-speed data of Table 5, the recurrence of Vehicle 65 suggests a problem with this MNA.

Considering the frequency of links, it appears that Links 3 and 10 continue to occur disproportionately. They represent the same road segment but travel is in opposite directions. Perhaps the shortness of the link is playing a role here. Note also that three of the four cases in Table 11 which have differences of less than 10% of the link length are during the 4pm to 6pm peak period. These reports may be accurately conveying congested conditions and should not be discarded. The other four reports (with especially large differences) occur during the off-peak and are less likely to be conveying highly congested conditions. Table 11, then, provides evidence for increasing the threshold for high congested distance from 25 meters to 10% of the link length. 'To the extent that distance is measured by an odometer, a distance based criterion such as link length makes sense.

During the week of July 17-20, of a total number of 8578 MNA reports collected, 49 contained high congested-distance reports (Table 12). Ten high congested-distance reports were received from Vehicle 20 and five high congested-distance reports were received from Vehicles 17 and 27. Four high congested-distance reports were received from Vehicles 9, 13, 22 and 23. Four links, 7, 8, 9 and 10 account for all except one of the

Table 11: High Congested Distance (CD 25m over link length): June 19-22

Date	Time	TT	CD	CT	Link		Vehicle		InT	InD	Difference	
					ID	Length	ID				(m)	%
6 19 95	15 46 26	399	485	341	31	403	16		0	0	82	20.3
6 19 95	17 54 38	91	431	28	10	403	65		0	0	28	6.9
6 20 95	15 22 57	108	430	7	10	403	23		0	0	27	6.7
6 20 95	16 30 20	93	502	1	31	403	13		0	0	99	24.6
6 20 95	17 45 55	375	905	216	9	856	17		0	0	49	5.7
6 20 95	17 58 30	261	554	200	7	520	87		0	0	34	6.5
6 21 95	18 56 30	227	510	145	31	403	16		0	0	107	26.6
6 22 95	14 3 13	594	2968	1	8	660	65		0	0	2308	350

Note: Difference = Congested Distance less the Link Length

high congested-distance reports recorded during this week in July. Twenty-four high congested-distance reports were recorded on Link 7; eleven high congested-distance reports were recorded on Link 10; eight high congested-distance reports were recorded on link 9; five high congested-distance reports were recorded on Link 8.

Twenty-six of the high congested-distance reports were coded for incident 1 - cycle failure, while the other twenty-three were without recorded incident codes. The three reports with greatest differences, all over 200 meters, lack an incident code, implying that these are faulty reports. Beyond this there are no other obvious patterns in the high CD reports but it is likely, given the high proportion of cycle failures recorded, that many of these reports accurately convey congested conditions and a flexible standard such as 10% above the link length should be used.

Table 12: High Congested Distance (CD 25m over link length): July 17-20

Date	Time	TT	CD	CT	Link		Vehicle		InT	InD	Difference	
					ID	Length	ID				(m)	%
7 17 95	17 4 20	271	588	135	7	520	13		1	180	68	13.1
7 17 95	17 11 12	316	958	112	9	856	17		0	0	102	11.9
7 17 95	17 27 6	316	623	236	7	520	20		0	0	103	19.8
7 17 95	15 0 49	122	445	4	10	403	19		0	0	45	11.2
7 18 95	15 2 10	110	489	4	10	403	13		0	0	86	21.3
7 18 95	16 1 58	343	556	244	7	520	20		1	130	36	6.9
7 18 95	16 30 41	339	551	264	7	520	16		1	180	31	6.0
7 18 95	16 30 41	341	764	170	7	520	22		1	360	244	46.9

Date	Time				Link		Vehicle				Difference	
		TT	CD	CT	ID	Length	ID		InT	InD	(m)	%
7 18 95	16 48 39	321	651	246	7	520	20		1	205	131	25.2
7 18 95	16 55 20	288	887	149	9	856	20		1	155	31	3.6
7 18 95	16 55 35	112	553	14	10	403	13		1	60	150	37.2
7 18 95	17 15 54	314	586	220	7	520	20		1	170	66	12.7
7 18 95	17 16 1	309	594	236	7	520	23		1	300	74	14.2
7 18 95	17 40 47	331	610	210	7	520	21		1	250	90	17.3
7 18 95	17 43 3	294	626	183	7	520	20		1	130	106	20.4
7 18 95	17 47 5	402	579	337	7	520	22		1	360	59	11.3
7 18 95	17 47 18	200	909	81	9	856	23		0	0	53	6.2
7 18 95	17 49 35	137	488	44	10	403	23		0	0	85	21.1
7 18 95	17 56 3	260	644	92	7	520	17		0	0	124	23.8
7 18 95	18 2 45	258	675	128	7	520	20		1	100	155	29.8
7 19 95	14 11 44	189	556	126	7	520	20		0	0	36	6.9
7 19 95	15 11 49	109	607	1	10	403	9		0	0	204	50.6
7 19 95	16 24 6	107	521	5	10	403	17		0	0	118	29.3
7 19 95	17 15 30	290	812	130	7	520	9		0	0	292	56.2
7 19 95	17 20 0	306	971	148	9	856	43		1	180	115	13.4
7 19 95	17 29 1	447	649	373	7	520	27		1	240	129	24.5
7 19 95	17 29 22	348	578	262	7	520	11		1	420	5s	11.2
7 19 95	17 36 9	349	844	127	7	520	22		0	0	324	62.3
7 19 95	17 45 10	349	911	228	9	856	22		1	300	53	6.4
7 19 95	17 51 4	397	575	310	7	520	13		1	65	55	10.6
7 19 95	17 54 4	115	443	35	10	403	43		0	0	40	9.9
7 19 95	15 5 15	420	658	341	7	520	65		1	375	138	26.5
7 19 95	18 16 23	329	600	190	7	520	17		1	105	80	15.4
7 20 95	15 9 7	92	501	2	10	403	14		0	0	9s	24.3
7 20 95	16 22 11	343	920	220	9	856	27		0	0	64	7.5
7 20 95	16 43 50	253	698	154	5	660	9		1	230	38	5.5
7 20 95	17 7 21	275	584	164	2	457	20		0	0	127	27.5
7 20 95	17 9 20	93	440	43	10	403	17		0	0	37	9.2
7 20 95	17 10 27	624	807	537	S	660	43		1	106	14i	22.3
7 20 95	17 12 29	622	689	531	S	660	27		0	0	29	4.4
7 20 95	17 15 51	327	1015	201	9	856	43		1	52	159	18.6
7 20 95	17 18 9	459	610	372	7	520	14		1	240	90	17.3
7 20 95	17 34 55	329	732	244	8	660	16		1	312	72	10.9
7 20 95	17 45 33	300	788	175	8	660	27		0	0	12s	19.4
7 20 95	17 51 49	114	462	68	10	403	s7		0	0	59	14.6
7 20 95	18 4 3	323	910	200	9	856	9		1	315	54	6.3
7 20 95	18 7 56	94	437	3	10	403	104		0	0	3-I	8.4
7 20 95	18 30 5	341	649	263	7	520	27		0	0	129	24.5
7 20 95	18 38 52	386	652	323	7	520	20		0	0	132	25.4

Rote: Difference = Congested Distance less the Link Length

#### 4.2.2 All Data

As a result of the factors discussed above? in the analysis of the complete data set only those reports that exceeded the link length by at least 10% were examined. Table 13 lists these high-CD reports for each link in the study area; together they account for less than 0.2% of all probe reports.

As the most congested link in the evaluation study area, Link 7 accounts for almost 40% of all high congested-distance reports. Link 10 accounts for another 30% of all high congested-distance reports recorded. The only other link where a significant number of such reports were recorded is Link 31, the 'same' section of road as Link 10 but in the opposite direction.

Table 13: Reports where CD exceeds link length by 10%: by Link\*\*

Link	Frequency	Percent		Link	Frequency	Percent
1	0	0		7	37	38.9
2	3	3.3		S	4	4.2
31 *	12	12.6		9	2	2.1
32 *	2	2.1		10	30	31.6
4	0	0		11	5	5.3
5	0	0		12	0	0
6	0	0				
				Total	95	100

\* 31 - short route (left turn)      \* 32 - long route (no turn)

\*\*\*Total link reports examined: 50,620

The number of high congested-distance reports (when congested distance reported for a link exceeds link length by more than 10%) for each vehicle used in the ten-week data-collection exercise is shown in Table 14. Vehicle 17 and Vehicle 10 each account for over 10% of all high congested-distance reports recorded during the entire study period; Vehicle 43 accounts for nearly 10% of all high congested-distance reports.

The number of reports when the congested distance recorded for a link is greater than link length, when it exceeds link length by 5% and when it exceeds link length by 10% is given in Table 15. This table indicates that even if a more stringent criterion of CD 5% greater than link length is used: the number of high-CD reports increases by only 36.

Table 22 in the Appendix lists all 95 high-CD reports, when congested-distance exceeds link length by more than 10%.

Table 14: Reports where CD exceeds link length by 10%: by Vehicle\*

Vehicle	Frequency	Percent		Vehicle	Frequency	Percent
9	4	4.2		22	7	7.4
10	3	3.2		23	3	3.2
11	2	2.1		27	6	6.3
13	7	7.4		40	1	1.1
14	2	2.1		43	9	9.5
16	5	5.3		65	6	6.3
17	13	13.7		66	2	2.1
19	1	1.1		80	1	1.1
20	10	10.5		87	4	4.2
21	6	6.3		92	3	3.2
				Total	95	100.0

\* Total link reports examined: 50,620

Table 15: Number of Reports in which Congested Distance exceeds Link Length

Ratio of CD to Link Length	Number of Reports
1.001 - 1.05	51
1.051 - 1.10	36
over 1.10	95
Total	182

### 4.3 Congested-Distance and Congested-Time Comparisons

There are also logical inconsistencies in the data which need to be considered. One is the relationship between congested distance and congested time. It is not likely that a vehicle which records a positive CT, having traveled under 5 mph or has stopped, has not recorded a positive CD, i.e., CD should be greater than zero. Of the 50,620 reports transmitted to the TIC from our study routes during the entire study period, there were 43 reports where a positive value is recorded for congested time and a value of zero is recorded for congested distance (Table 16). All but one of these 43 reports was recorded by Vehicle 6.5. We considered AASHTO specifications and other alternatives and could not determine with accuracy the minimum distance traveled by a vehicle accelerating and decelerating between 22.5 mph and 5 mph. Table 16 provides us with clues. Up to a CD value of approximately 21-25 meters, Vehicle 65 accounts for most of the records. This suggests a faulty MNA. Over 25 meters the reports are distributed among a large number of vehicles. This suggests approximately 115 faulty reports on this criterion, from the first six rows in Table 16. These 115 reports account for only 0.2% of all the probe reports.

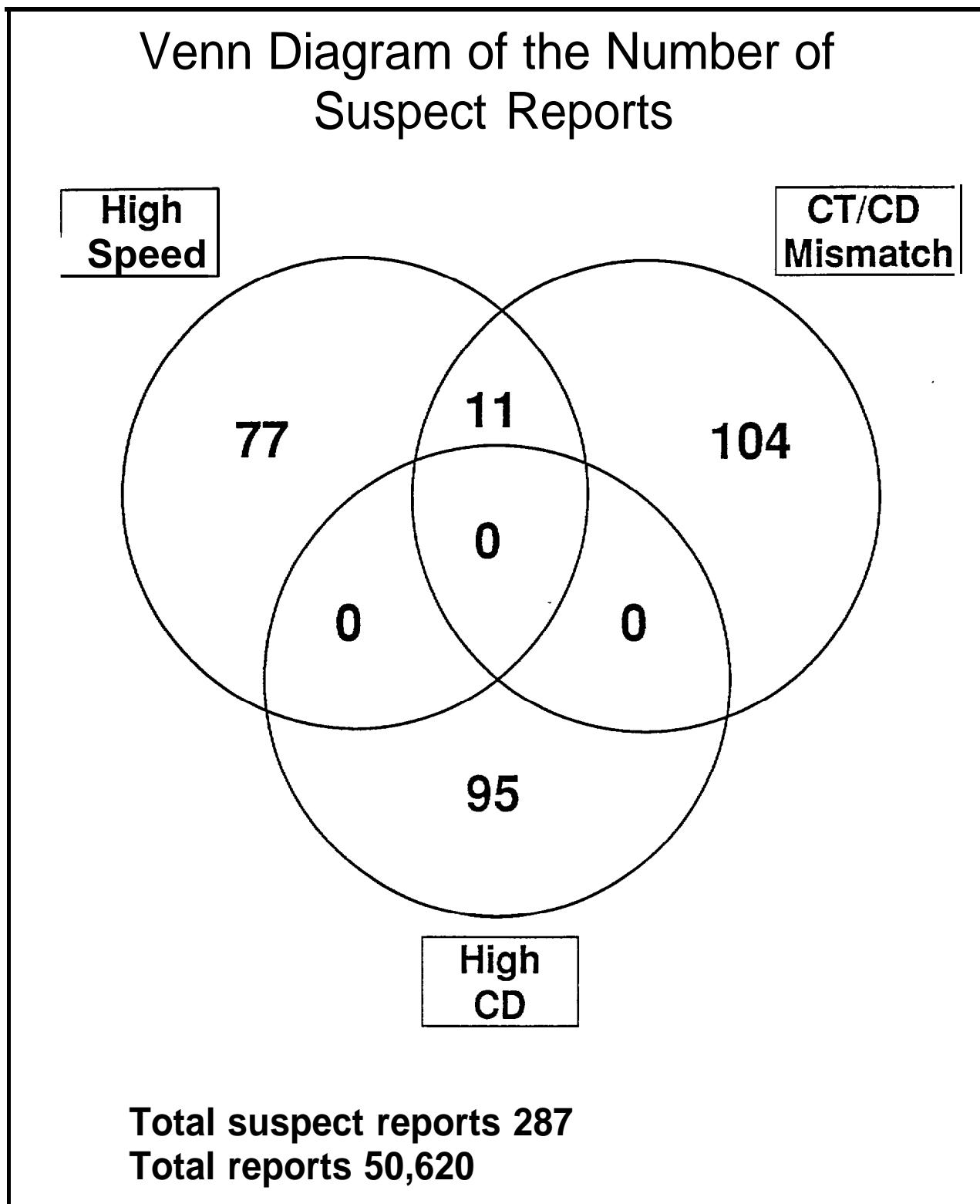
Table 16: Congested Distance when Congested Time is Positive

CD (m)	Total Number of Reports	--Number of Reports--				
		Veh 65	Veh 13	Veh 21	Veh 11	Veh 43
0	43	42	0	0	0	0
1 - 5	9	5	0	0	0	0
6 - 10	11	10	0	1	0	0
11 - 15	11	9	1	0	0	0
16 - 20	11	4	1	1	0	0
21 - 25	30	6	2	1	2	3
26 - 30	82	9	5	8	6	6
31 - 35	166	17	8	13	11	15

### 4.4 Summary

Three criteria were applied to detect faulty reports. Each identified approximated one hundred reports which appear incorrect. Some of these reports, however: were identified more than once. If the MNA malfunctioned it is reasonable to expect that it may affect more than one item in the report. Figure 5 illustrates the degree of overlap in the flagged data. It shows that there is only one common area: between high speeds and CT/CD mismatch. The eleven reports here indicate that the vehicle was traveling over 55mph and that it also recorded congested time but did not have a sufficient congested distance to permit decelerating from 22.5mph to 4.4mph and again resuming a speed over 22.5mph. Other than this overlap the suspected faulty reports appear to be independent of each other.

**Figure 5:**



## 5 Observer Comparisons

In the previous section the focus was on suggesting guidelines for discarding faulty records. In this section the emphasis is on assessing the comparability of probe and human-observer data. This is, however, not an exact science. When there is a difference between the probe and observer data much of it must be attributed to measurement error so there must be a reasonable range of acceptable differences. Also, when major differences occur it is not frequently possible to ascertain which is correct. This comparison is, nevertheless, an important phase of the evaluation process and it further supports the utility of the probe data.

### 5.1 Travel-Time Comparisons

The travel times manually recorded by observers traveling as passengers in the probe vehicles were compared with MNA travel-time reports. In order to do this the manually-recorded travel times were added to the reduced MNA data files; the resulting data files were then analyzed.

The analysis showed that average difference in travel times (MNA minus observer travel times) is 0.4 seconds with a standard deviation of 5.5 seconds ( $n = 776$ ). Approximately seven of every eight differences (87.6%) were within  $\pm 5$  seconds and 94% were within  $\pm 10$  seconds. Distribution of the difference between the MNA recorded travel times and the observer-recorded travel times is shown in Figure 6 and the 87.6% of the reports with differences less than five seconds are shown in Table 17. These indicate there is a good fit between observer and MNA travel-time reports.

#### 5.1.1 Observer Travel-Time Comparison by Link

The distribution of the difference between the MNA-recorded travel times and the manually-recorded travel times for each of the twelve links is shown in Tables 23 to 34 in the Appendix (the manually-recorded travel time data collected is summarized in Table 4). These tables show that over 85% of the manually-recorded travel times were within  $\pm 5$  seconds of the travel times recorded by the MNA for all but two of the study route links - Link 7 and Link 8. It is possible that the right turn on red may have caused some uncertainty about when the vehicle reached the end of Link 7 and began Link 8. Such uncertainty could have substantially affected both links.

Considering the average difference between the probe and observer travel times by link, four links have values greater than or equal to 1.0 second. These are Link 2 (-1.0 seconds), Link 7 (2.4 seconds), Link 10 (1.3 seconds) and Link 12 (1.5 seconds). It is understandable that Link 7, with the highest travel times, due more to congestion than length, also has the greatest average difference.

Table 17: Distribution of Travel-Time Differences

	Difference	No. of Reports	% of Total Reports
	-5	20	2.6
	-4	26	3.4
	-3	39	5.0
	-2	73	9.4
	-1	105	13.5
	0	101	13.0
	+1	102	13.1
	+2	50	10.3
	+3	73	9.4
	+4	40	5.2
	+5	21	2.7
Total			87.6

Note: Difference = MNA travel time less observer-recorded travel time (in seconds)

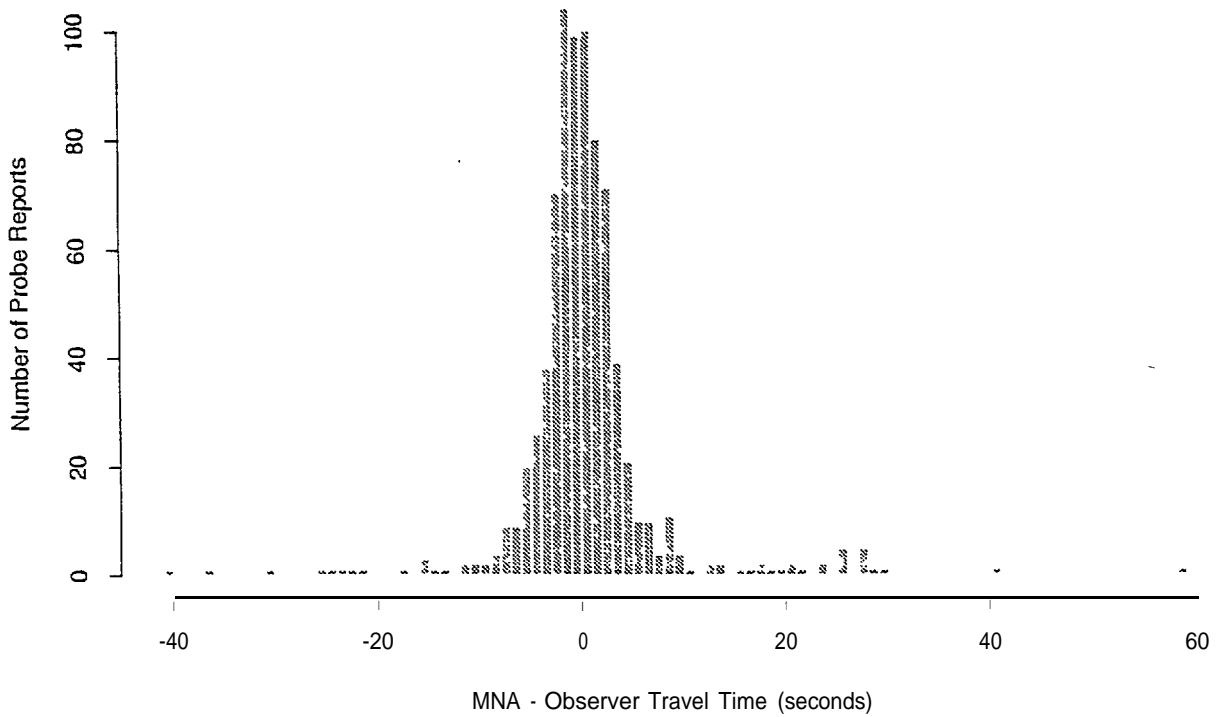


Figure 6: Distribution of Travel-Time Differences

### 5.1.2 Observer Travel-Time Comparison by Vehicle

The distribution of the difference between the MNA-recorded travel times and the manually-recorded travel times for each of the twelve probe vehicles used in the data-collection exercise is shown in Tables 35 to 46 in the Appendix (the manually-recorded travel time data collected is summarized in Table 4). These tables show that over 85% of the manually-recorded travel times were within  $\pm 5$  seconds of the travel times recorded by the MNA for all but three of the vehicles used in quality of probe reports data collection; Vehicles 11, 21 and 87. For Vehicle 11 62.7% of the manually-recorded travel times were within  $\pm 5$  seconds of the MNA-recorded travel time. For Vehicle 21 67.5% of the manually-recorded travel times were within  $\pm 5$  seconds of the MNA-recorded travel time. For Vehicle 87, 77.3% of the manually-recorded travel times were within  $\pm 5$  seconds of the MNA-recorded travel time.

The same observer - observer number 3 - is responsible for all manually-recorded travel times in Vehicles 11 and 21, and for over half of all the manually-recorded travel times in Vehicle 87 (100 minutes out of 158 minutes of manual data collection - see Table 4). It therefore appears likely that we have a problem with a bad observer rather than a problem with the MNA in these vehicles. This further supports the conclusion that the MNAs are functioning well.

This conclusion is reinforced by examining the average differences between probe and observer travel times by vehicle and contrasting it to the examination above of differences by link. Of the twelve vehicles tested, Vehicle 23 had the greatest average difference of 1.4 seconds and Vehicle 11 was next with 1.3 seconds. These differences are smaller than the differences found above -by link. where the highest value was 2.4 seconds. It appears that the MNA is working well: the link differences are greater than the vehicle differences. Moreover, it appears that probe data are more consistently correct than human observations. Humans may be distracted more often than machines are faulty.

### 5.1.3 Observer Travel-Time Comparisons: Turning-Relationships Route

On one day during data collection on the turning relationships route (Figure 3), manual observations of travel times were made. One observer traveled as a passenger in several different vehicles. The link travel times noted by this observer were compared with MNA travel-time reports.

The analysis showed that only 75% of the manually-recorded travel times were within  $\pm 5$  seconds of the travel times recorded by the MNA. The distribution of the differences between the MNA-recorded travel times and the manually-recorded travel times for the observations made on the turning relationships route is given in Table 18. These data were not combined with the earlier analysis because there were an unusually large number of turns and these turns contribute to differences between MNA and observer travel-time data.

The same observer - observer number 25 - was responsible for all manually-recorded travel-time data on the turning-relationships route. Because the task was made more difficult by the high number of turns: we expected and found the percentage of reports within five seconds to be lower. We are satisfied with the result.

Table 18: Distribution of Travel-Time Differences: Turning-Relationships Route

	Difference	No. of Reports	% of Total Reports
	-5	1	1.1
	-4	3	3.4
	-3	1	1.1
	-2	4	4.5
	-1	9	10.25
	0	10	11.4
	+1	14	15.9
	+2	12	13.6
	+3	7	8.0
	+4	4	4.5
	+5	1	1.1
Total:			74.8

Difference = MNA travel time less observer-recorded travel time (in seconds).

## 5.2 Congested-Distance Comparisons

Congested distance is the distance the vehicle travels at speeds of less than ten meters per second (36 kilometers per hour or 22.5 miles per hour). In order to validate the MNA congested distance (CD) the vehicle needs to move at below this speed between known markers for which the distance is known or can be easily be measured. It was exceptionally difficult to perform this driving activity to any level of precision. The first two sets of records ( June 1 and August 24) on Table 19 were derived by changing speeds several times above and below ten meters per second. Not surprisingly the observer and MNA data do not match particularly well. The differences can be easily attributed to both the distance computation system in the vehicle and the difficulty in making the vehicle perform at required speeds between the exact markers on the link.

It was much easier to evaluate the performance of the MNA by driving the entire link at speeds under ten meters per second. This is reported on Table 19 for the September 29 and October 13 dates. While these congested distances are unrealistically long for normal driving conditions, they deviate up to 25 meters from the link length (observed

Table 19: Comparison of Observer and MNA Congested Distances

Date	Vehicle ID	Observer Distance	MNA Distance
June 1	16	315	296
June 1	16	315	339
June 1	16	315	290
June 1	16	210	228
Aug 24	19	245	285
Aug 24	19	245	228
Aug 24	19	245	267
Xug 24	19	245	247
Aug 24	19	245	228
Aug 24	19	245	155
Aug 24	19	245	256
Aug 24	19	245	266
Aug 24	19	245	206
Aug 24	19	245	213
Aug 24	19	245	237
Aug 24	19	245	256
xug 24	19	245	230
Aug 24	19	245	228
Sept 29	84	280	249
Sept 29	84	280	298
Sept 29	84	280	307
Sept 29	84	280	281
Oct 13	22	690	705
Oct 13	22	690	686
Oct 13	22	690	689
Oct 13	22	690	661
Oct 13	22	690	681
Oct 13	22	690	718
Oct 13	22	535	512
Oct 13	22	535	568
Oct 13	22	535	570
Oct 13	22	535	548
Oct 13	22	535	533
Oct 13	22	535	551
Oct 13	22	225	245
Oct 13	22	225	23s
Oct 13	22	225	209
Oct 13	22	225	245
Oct 13	22	225	243
Oct 13	22	225	217

distance). This suggests that this measurement has more variability than the travel time and that measuring short CDs would likely be characterized by large percentage differences between observer and MNA data.

It was also easy to simulate the  $CD=0$  condition. In this case the vehicle traverses the link without slowing to less than ten meters per second. This is not at all an unusual condition having occurred for 16.7% of the links during the summer driving period (9455 of the 50,620 reports examined). In the several dozens of times in which we performed the  $CD=0$  test the MNA detected no CD. We were satisfied that the MNA performed very well in measuring congested distance.

### **5.3 Congested-Time Comparisons**

Congested time, the duration the vehicle travels at speeds less than 2 meters per second, is much easier to assess because this is very close to being immobile. In most instances the bulk of the CT is logged while the vehicle is at a complete stop. CT is equal to zero in 35.7% of the links examined ( $n=20,243$ ) and it is less than ten seconds in a total of 27,991 links or in nearly half of the link reports examined.

There was generally close correspondence between observer logs and MNA congested time data. Given the imprecision of noting the exact time the vehicle drops below the critical speed it is almost remarkable that the observer and MNA data are so close. The log and MNA congested distance reports for one vehicle (Vehicle 84) can be seen in Table 20 and for all the data collected on Figure 7.

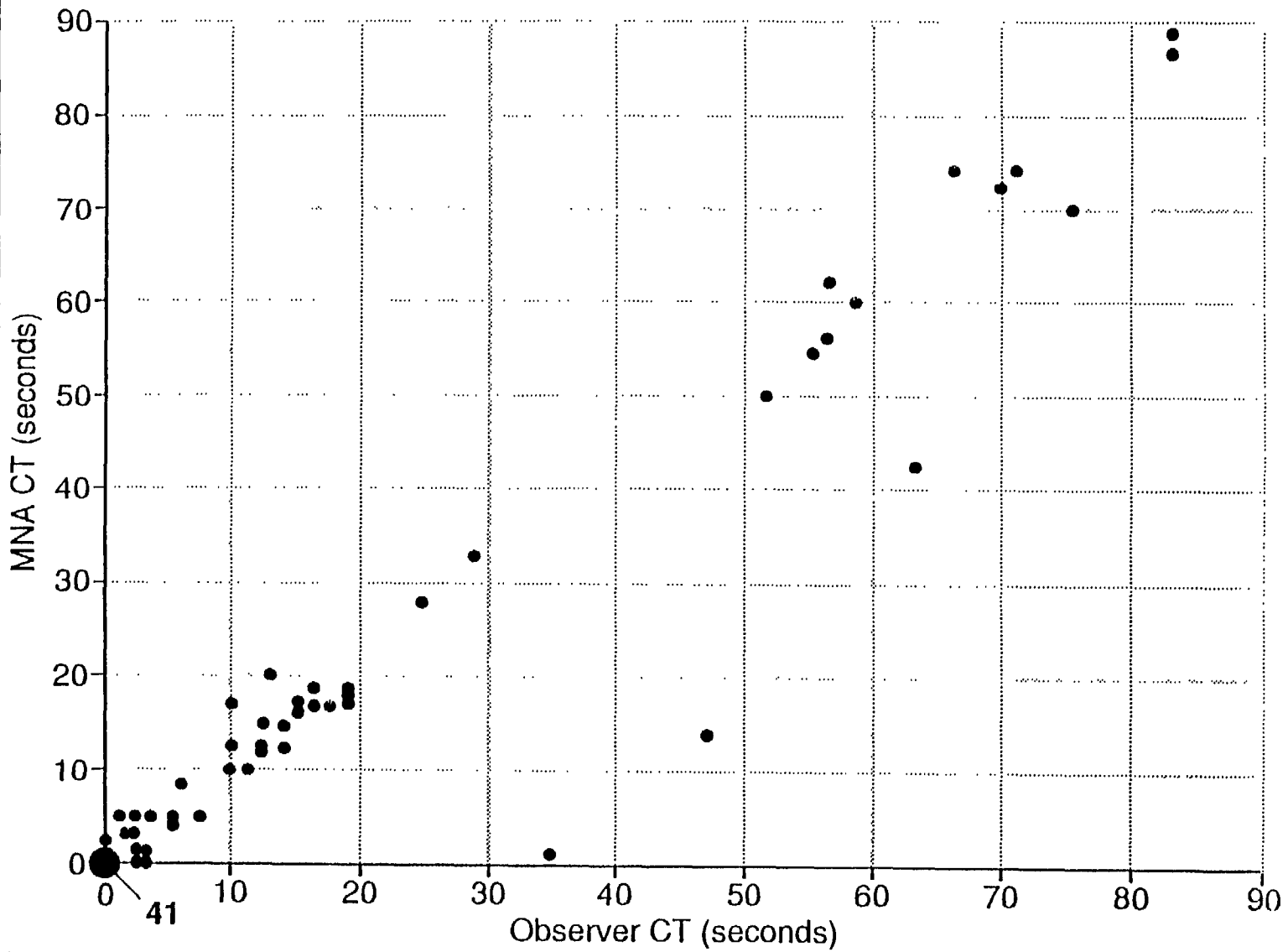
One of the vehicles accounts for three outliers on Figure 7. Since these represent the greatest difference between observer and MNA data the general assessment here is that the MNA reports the CT very well. This is especially the case since there is no good means to determine whether the three outliers can be attributed to the MNA or the observer.

Table 20: Comparison of Observer and MNA Congested Times (CT)

Date	Vehicle	MNA CT	Observed CT
Sep 29	84	4	4
Sep 29	S4	50	52
Sep 29	84	20	14
Sep 29	84	15	10
Sep 29	84	14	14
Sep 29	84	53	56
Sep 29	84	106	109
Sep 29	34	0	2
Sep 29	84	12	14
Sep 29	84	0	2
Sep 29	84	61	58
Sep 29	84	5	6
Sep 29	84	0	2
Sep 29	84	16	17
Sep 29	S4	4	5
Sep 29	84	0	2

Congested travel times is the time [in seconds) the vehicle speed is less than two meters per second

Figure 7: Relationship Between Observer and MNA Congested Time (CT)



## 6 Conclusion

This study examined 50,620 link reports collected during an eleven-week period in the summer of 1995. The driving occurred during the hottest part of the day, the afternoon and early evening, in a summer which was one of the hottest on record. Indeed, the 106°F temperature recorded on one of the data-collection days was the hottest official temperature recorded in Chicago. Many other days were over 100°F and the MNA temperatures reached 150°F in some vehicles. Despite these extreme conditions, the equipment performed well.

Two types of quality assessments were performed. The first considered the reasonableness of the data by evaluating speed and two congestion measures. The second assessment compared the probe data to data recorded by human observers. This latter test requires human judgement and the use of measuring devices and it therefore cannot be considered to be an exact measurement. It is, however, an important evaluation step as it provides useful information.

The first evaluation was performed on all 50,620 reports and found the data to be exceptionally good. If 1% of the reports are determined to be faulty then with the number of records examined this would sum to 506 records. None of the suspicious speed, CT and CD conditions imposed here uncovered more than 125 problem records. Together they account for less than three hundred records or only approximately one half of one percent. This is a commendable achievement.

Currently the data files include all data collected. Nothing has been deleted. If a simple screen is imposed then the problem records can be discarded and the data can be used in this reduced form. For someone interested in all the recorded information it is intact. Some of these faulty records likely do not provide much useful information. If an MNA report exceeded the speed limit by a substantial margin then even if this accurately reflects probe activity it would probably happen during the off-peak when cruise-time conditions are anticipated and would not contribute much information. Other reports on high CDs or illogical matches between CT and CD may be reflecting highly congested conditions and the deletion of these reports would be more problematic. In a case in which the CD value is too high but there is severe congestion, discarding this record would actually eliminate potentially useful information.

We recommend that users make their own decisions about which reports to delete. This study suggests the following. Delete reports if the speeds exceed 55mph, the CD exceeds link length by 10% and the CD is less than 25 meters when the CT is positive.

In the second evaluation phase, using human observers, the results were also good but not quite as conclusive as in the first phase. Considering travel time on the link and both congested time and congested distance the conclusion is that the match is sufficiently good between probe and human-observer data that the MNA data are a reliable indicator of travel conditions.

In sum, a substantial amount of data was collected during the summer months. In these data are some faulty records. The faulty records constitute a very small

proportion of the total data collected and they can be easily detected and deleted. As a whole the probe-vehicle data represent an especially valuable resource for traffic analysis and we anticipate considerable interest in these data.

## Appendix

### Memory Card Data compared to TIC Data

During the core period, from 2:00 pm to 7:00 pm, Vehicle 17 recorded 115 TIC link reports and 119 memory card reports (Table 21). More importantly during the key 4:00 pm to 6:00 pm peak period (16:00 to 17:59) there was a difference of only one report. There appeared to be no apparent reason, based on the route of the vehicle, for the missing TIC reports. The small sample size would not permit generalizations about reasons for missing reports. The difference in the number of reports is small at less than 5%.

Table 21: Memory Card v. TIC: Vehicle 17, July 20, 1995

Time	TIC Reports	Memory Card Reports
13:00-13:59	22	22
14:00-14:59	34	34
15:00-15:59	16	17
16:00-16:59	30	31
17:00-17:59	18	18
18:00-18:59	17	19
19:00-19:59	13	13

Table 22: Reports for which Congested Distance is more than 10% greater than Link Length

No	TT	CD	CT	Link ID	Link Length	Vehicle	InT	InD	Ratio
1	170	507	119	2	457	92	0	0	1.10941
2	127	537	30	2	457	21	0	0	1.17505
3	275	584	164	2	457	20	0	0	1.27790
4	407	573	333	7	520	43	1	240	1.10192
5	277	575	207	7	520	20	0	0	1.10577
6	397	575	310	7	520	19	1	65	1.10577
7	348	578	262	7	520	11	1	420	1.11154
8	402	579	337	7	520	22	1	360	1.11346
9	314	586	220	7	520	20	1	170	1.12692
10	271	588	135	7	520	13	1	180	1.13077
11	388	589	309	7	520	43	0	0	1.13269
12	340	591	220	7	520	21	1	420	1.13654
13	309	594	236	7	520	23	1	300	1.14231
14	263	600	191	7	520	21	1	120	1.15385
15	329	600	190	7	520	17	1	105	1.15385
16	381	608	313	7	520	17	1	210	1.16923
17	151	609	1	7	520	87	0	0	1.17115
18	331	610	210	7	520	21	1	250	1.17308
19	459	610	372	7	520	14	1	240	1.17308
20	324	615	259	7	520	9	0	0	1.18269
21	337	620	213	7	520	43	1	315	1.19231
22	316	623	236	7	520	20	0	0	1.19808
23	294	626	183	7	520	20	1	130	1.20385
24	362	634	277	7	520	27	1	300	1.21923
25	260	644	92	7	520	17	0	0	1.23846
26	447	649	373	7	520	27	1	240	1.24508
27	341	649	263	7	520	27	0	0	1.24808
28	321	651	246	7	520	20	1	205	1.25192
29	336	652	323	7	520	20	0	0	1.25385
30	420	658	341	7	520	65	1	375	1.26538
31	345	666	272	7	520	43	1	180	1.28077
32	258	675	128	7	520	20	1	100	1.29805
33	334	680	204	7	520	11	0	0	1.30769
34	351	692	270	7	520	17	1	180	1.33077
35	595	697	527	7	520	65	1	465	1.34038
36	341	764	170	7	520	22	1	360	1.46923
37	345	812	153	7	520	22	1	180	1.56154
38	290	812	130	7	520	9	0	0	1.56154
39	413	842	264	7	520	87	0	0	1.61923
40	349	844	127	7	520	22	0	0	1.62308

No	TT	CD	CT	Link ID	Link Length	Vehicle	InT	InD	Ratio
41	329	732	244	8	660	16	1	312	1.10909
42	300	788	175	8	660	27	0	0	1.19394
43	524	307	237	8	660	43	1	106	1.22273
44	594	968	1	8	660	65	0	0	1.46667
45	316	358	112	9	856	17	0	0	1.11785
46	306	971	148	9	856	43	1	180	1.13302
47	98	147	4	10	403	43	0	0	1.10918
48	110	148	2	10	403	80	0	0	1.11166
49	122	248	4	10	403	19	0	0	1.11166
50	55	249	2	10	403	10	0	0	1.11414
51	114	155	26	10	403	13	0	0	1.12903
52	76	256	2	10	403	66	0	0	1.13151
53	139	456	43	10	403	92	0	0	1.13151
54	114	462	68	10	403	87	0	0	1.14640
55	91	466	4	10	403	23	0	0	1.15633
56	103	476	5	10	403	17	0	0	1.18114
57	287	477	237	10	403	16	4	120	1.18362
58	96	179	1	10	403	66	0	0	1.18859
59	137	488	44	10	403	23	0	0	1.21092
60	110	489	4	10	403	13	0	0	1.21340
61	92	501	2	10	403	14	0	0	1.24318
62	162	510	44	10	403	22	1	60	1.26551
63	91	514	4	10	403	10	0	0	1.27543
64	104	515	1	10	403	40	0	0	1.27792
65	107	521	8	10	403	17	0	0	1.29280
66	147	548	48	10	403	27	6	60	1.35980
67	112	553	14	10	403	13	1	60	1.37221
68	93	564	1	10	403	10	0	0	1.39950
69	108	570	8	10	403	21	0	0	1.41439
70	104	576	2	10	403	13	0	0	1.42928
71	106	597	2	10	403	17	0	0	1.48139
72	109	607	1	10	403	9	0	0	1.50620
73	155	648	58	10	403	17	0	0	1.60794
74	230	668	70	10	403	65	0	0	1.65757
75	647	707	604	10	403	43	4	540	1.75434
76	292	735	241	10	403	87	4	243	1.82382
77	87	511	2	11	457	17	0	0	1.11816
78	154	311	107	11	457	65	1	60	1.11816
79	140	529	29	11	457	65	0	0	1.15270
80	181	552	62	11	457	21	0	0	1.20788

No	T T	CD	CT	Link ID	Link Length	Vehicle	InT	InD	Ratio
81	165	612	55	1 1	457	17	5	60	1.33917
82	322	460	260	31	403	22	0	0	1.14144
83	160	466	46	31	403	9	4	65	1.15633
84	399	485	341	31	403	16	0	0	1.20347
85	676	491	639	31	403	17	4	510	1.21836
86	93	502	1	31	403	13	0	0	1.24566
87	170	507	68	31	403	27	0	0	1.25806
88	22i	510	145	31	403	16	0	0	1.26551
89	118	527	14	31	403	20	0	0	1.30769
90	131	535	25	31	403	92	0	0	1.32754
91	103	543	3	31	403	20	0	0	1.34739
92	638	548	508	31	403	43	0	0	1.35980
93	384	611	351	31	403	22	5	60	1.51613
94	132	469	87	32	403	16	4	85	1.16377
95	247	528	210	32	403	17	4	240	1.31017

Table 23: Distribution of Travel-Time Differences (in seconds): Link 1

	Difference	No. of Reports	% of Total Reports
	-5	0	0
	-4	1	1.4
	-3	2	2.7
	-2	3	4.1
	-1	7	9.5
	0	7	9.5
	+1	15	20.3
	+2	15	20.3
	+3	7	9.5
	+4	5	6.8
	+5	2	2.7
Total			86.8

Table 24: Distribution of Travel-Time Differences (in seconds): Link 2

	Difference	No. of Reports	% of Total Reports
	-5	2	2.3
	-4	6	6.3
	-3	6	6.3
	-2	13	13.9
	-1	11	11.6
	0	10	10.5
	+1	6	6.3
	+2	4	4.2
	+3	5	5.3
	+4	1	1.1
	+5	0	0
Total			88.9

Table 25: Distribution of Travel-Time Differences (in seconds): Link 3

	Difference	No. of Reports	% of Total Reports
	-5	3	4.3
	-4	3	4.3
	-3	3	4.3
	-2	2	2.9
	-1	14	20
	0	10	14.3
	+1	9	12.9
	+2	6	8.6
	+3	6	8.6
	+4	5	7.1
	+5	3	4.3
Total			91.6

Table 26: Distribution of Travel-Time Differences (in seconds): Link 4

	Difference	No. of Reports	% of Total Reports
	-3	2	3.7
	-4	3	5.6
	-3	2	3.7
	-2	3	5.6
	-1	2	3.7
	0	12	22.2
	+1	9	16.7
	+2	7	13.0
	+3	6	11.1
	+4	4	7.4
	+5	2	3.7
Total			96.4

Table 27: Distribution of Travel-Time Differences (in seconds): Link 5

	Difference	No. of Reports	% of Total Reports
	-5	2	3.5
	-4	2	3.5
	-3	6	10.5
	-2	9	15.8
	-1	12	21.1
	0	10	17.5
	+1	3	5.3
	+2	4	7.0
	+3	2	3.5
	+4	2	3.5
	+5	1	1.8
Total:			93.0

Table 28: Distribution of Travel-Time Differences (in seconds): Link 6

	Difference	No. of Reports	% of Total Reports
	-5	1	1.6
	-4	2	3.3
	-3	2	3.3
	-2	8	13.1
	-1	15	24.6
	0	8	13.1
	+1	5	8.2
	+2	5	8.2
	+3	3	4.9
	+4	3	4.9
	+5	0	0
Total:			85.2

Table 29: Distribution of Travel-Time Differences (in seconds): Link 7

	Difference	No. of Reports	% of Total Reports
	-5	1	1.6
	-4	0	0
	-3	0	0
	-2	2	3.2
	-1	4	6.5
	0	4	6.5
	+1	9	14.5
	+2	10	16.1
	+3	8	12.9
	<del>+4</del>	7	11.3
	+ 5	4	6.5
Total			79.1

Table 30: Distribution of Travel-Time Differences (in seconds): Link 8

	Difference	No. of Reports	% of Total Reports
	-5	4	7.7
	-4	2	3.8
	-3	3	5.8
	-2	<b>7</b>	13.5
	-1	9	17.3
	0	<b>7</b>	13.5
	+1	5	9.6
	+ 2	3	5.8
	+ 3	1	1.9
	<del>+4</del>	1	1.9
	+5	0	0
Total			80.8

Table 31: Distribution of Travel-Time Differences (in seconds): Link 9

	Difference	No. of Reports	% of Total Reports
	-5	2	3.8
	-4	3	5.7
	-3	4	7.5
	-2	11	20.8
	-1	9	17.0
	0	1	1.9
	+1	3	5.7
	+2	3	5.7
	+3	2	3.8
	+4	3	5.7
	+5	3	5.7
Total			83.3

Table 32: Distribution of Travel-Time Differences (in seconds): Link 10

	Difference	No. of Reports	% of Total Reports
	-5	0	0
	-4	1	1.4
	-3	3	4.2
	-2	7	9.9
	-1	5	7.0
	0	11	15.5
	+1	7	9.9
	+2	12	16.9
	+3	10	14.1
	+4	3	4.2
	+5	2	2.8
Total			55.9

Table 33: Distribution of Travel-Time Differences (in seconds): Link 11

	Difference	No. of Reports	% of Total Reports
	-5	2	2.6
	-4	2	2.6
	-3	6	7.9
	-2	8	10.5
	-1	9	11.8
	0	12	15.8
	+1	15	19.7
	+2	4	5.3
	+3	10	13.2
	+4	1	1.3
	+5	1	1.3
Total:			92.0

Table 34: Distribution of Travel-Time Differences (in seconds): Link 12

	Difference	No. of Reports	% of Total Reports
	-5	1	1.4
	-4	1	1.4
	-3	2	2.7
	-2	0	0
	-1	8	10.8
	0	9	12.2
	+1	16	21.6
	+2	7	9.5
	+3	13	17.6
	+4	5	6.8
	+5	3	4.1
Total:			88.1

Table 35: Distribution of Travel-Time Differences: Vehicle 10

	Difference	No. of Reports	% of Total Reports
	-5	2	1.9
	-4	2	1.9
	-3	6	5.8
	-2	10	9.6
	-1	17	16.3
	0	12	11.5
	+1	13	12.5
	+2	10	9.6
	+3	12	11.5
	+4	5	4.8
	+ 5		1.0
Total			86.4

Table 36: Distribution of Travel-Time Differences: Vehicle 11

	Difference	No. of Reports	% of Total Reports
	-5	1	4.2
	-4	0	0
	-3	0	0
	-2	0	0
	- 1	4	16.7
	0	4	16.7
	+1	1	4.2
	+ 2	0	0
	+3	4	16.7
	+4	1	4.2
	+5	0	0
Total			62.7

Table 37: Distribution of Travel-Time Differences: Vehicle 13

	Difference	No. of Reports	% of Total Reports
	-5	2	3.1
	-4	3	4.7
	-3	3	4.7
	-2	5	7.8
	-1	12	18.8
	0	7	10.9
	+1	14	21.9
	+2	4	6.3
	+3	4	6.3
	+4	1	1.6
	+5	2	3.1
Total			89.2

Table 38: Distribution of Travel-Time Differences: Vehicle 16

	Difference	No. of Reports	% of Total Reports
	-5	1	2.1
	-4	3	6.4
	-3	3	6.4
	-2	5	10.6
	-1	1	2.1
	0	6	12.5
	+1	6	12.8
	+2	6	12.8
	+3	4	5.5
	+4	4	8.5
	+5	1	2.1
Total			85.1

Table 39: Distribution of Travel-Time Differences: Vehicle 17

	Difference	No. of Reports	% of Total Reports
	-5	2	3.9
	-4	1	2.0
	-3	4	7.8
	-2	5	9.8
	-1	6	11.8
	0	6	11.8
	+1	10	19.8
	+2	7	13.7
	+ 3	6	11.8
	+4	1	2.0
	+5	2	3.9
<b>Total</b>			<b>98.1</b>

Table 40: Distribution of Travel-Time Differences: Vehicle 20

	Difference	No. of Reports	% of Total Reports
	-5	1	1.2
	-4	1	1.2
	-3	5	6.2
	-2	6	7.4
	-1	14	17.3
	0	14	17.3
	+1	9	11.1
	+2	9	11.1
	+3	4	4.9
	+4	4	4.9
	+5	3	3.7
<b>Total</b>			<b>56.3</b>

Table 41: Distribution of Travel-Time Differences: Vehicle 21

	Difference	No. of Reports	% of Total Reports
	-5	1	2.7
	-4	1	2.7
	-3	3	8.1
	-2	2	5.4
	-1	3	8.1
	0	1	2.7
	+1	4	10.8
	+2	3	8.1
	+3	4	10.8
	+4	3	8.1
		0	0
<b>Total</b>			<b>67.5</b>

Table 42: Distribution of Travel-Time Differences: Vehicle 23

	Difference	No. of Reports	% of Total Reports
	- 5	1	2.0
	-4	2	4.1
	- 3	2	4.1
	-2	4	5.2
	-1	8	16.3
	0	1	14.3
	+1	6	12.2
	+2	4	5.2
	+ 3	5	10.2
	<del>+4</del>	3	6.1
	+ 5	4	3.2
<b>Total</b>			<b>93.9</b>

Table 43: Distribution of Travel-Time Differences (in seconds): Vehicle 27

	Difference	No. of Reports	% of Total Reports
	-5	2	1.8
	-4	4	3.6
	-3	3	2.7
	-2	21	19.1
	-1	12	11.8
	0	16	14.5
	+1	15	13.6
	+2	16	14.5
	+3	11	10.0
	+4	7	6.4
	+5	2	1.8
Total:			100

Table 44: Distribution of Travel-Time Differences (in seconds): Vehicle 43

	Difference	No. of Reports	% of Total Reports
	-5	0	0
	-4	3	6.4
	-3	0	0
	-2	4	8.5
	-1	9	19.1
	0	7	14.8
	+1	4	8.5
	+2	6	12.8
	+3	7	14.9
	+4	1	2.1
	+5	3	6.4
Total:			93.6

Table 45: Distribution of Travel-Time Differences (in seconds): Vehicle 65

	Difference	No. of Reports	% of Total Reports
	-5	2	3.8
	-4	2	3.8
	-3	2	3.8
	-2	5	9.6
	-1	6	11.5
	0	8	15.4
	+1	5	9.6
	+2	5	9.6
	+3	6	11.5
	+4	4	7.7
	+5	3	5.8
Total:			92.1

Table 46: Distribution of Travel-Time Differences (in seconds): Vehicle 87

	Difference	No. of Reports	% of Total Reports
	-5	5	4.5
	-4	4	3.6
	-3	8	7.3
	-2	6	5.5
	-1	12	10.9
	0	13	11.8
	+1	15	13.6
	+2	10	9.1
	+3	6	5.5
	+4	6	5.5
	+5	0	0
Total:			77.3